DMU User's Manual

Models...

IMU700CA-

VG700CA-

(DMU-FOG)

Revision B, September 2002

Document 7430-0070-01

Crossbow

Crossbow Technology, Inc., 41 E. Daggett Dr., San Jose, CA 95134
Tel: 408-965-3300, Fax: 408-324-4840
email: info@xbow.com, website: www.xbow.com

©2002-2003 Crossbow Technology, Inc. All rights reserved.
Information in this document is subject to change without notice.

Crossbow and SoftSensor are registered trademarks and DMU is a trademark of Crossbow Technology, Inc. Other product and trade names are trademarks or registered trademarks of their respective holders.

Table of Contents

1 Introduction....1

1.1 The DMU™ Series Motion and Attitude Sensing Units....1

1.2 Package Contents....1

2 Quick Start....3

2.1 GyroView Software....3

2.1.1 GyroView Computer Requirements....3

2.1.2 Install GyroView....3

2.2 Connections....3

2.3 Setup GyroView....4

2.4 Take Measurements....4

3 DMU Details....6

3.1 DMU Coordinate System....6

3.2 Connections....6

3.3 Interface....9

3.4 Measurement Modes....9

3.4.1 Voltage Mode....9

3.4.2 Scaled Sensor Mode....10

3.4.3 Angle Mode (VG700CA Only)....11

3.5 Commands....12

3.5.1 Command List....12

3.6 Data Packet Format....15

3.7 Timing....18

3.8 Temperature Sensor....18

3.9 Analog Output....19

3.9.1 "Raw" Accelerometer Voltage....19

3.9.2 Scaled Accelerometer Voltage....19

3.9.3 Scaled Rate Sensor Voltage....20

3.9.4 Stabilized Pitch and Roll Voltages (VG models)....20

3.10 Adaptive-T Algorithm (for VG700 Series, installed at Crossbow factory)....21

4 DMU Operating Tips....22

4.1 The "Zero" Command....22

4.2 The Erection Rate (VG700CA only) 22
4.3 Mounting the DMU 23
4.4 DMU Start Up Procedure 24
4.5 Advanced Strategies for Adjusting the Erection Rate (VG models) 24
4.6 Adapted Flight Profile T-Setting 26

5 Appendix A. Mechanical Specifications 28

5.1 IMU700CA and VG700CA Outline Drawing 28

6 Appendix B. DMU Output Quick Reference 29

6.1 Analog Output Conversion 29
6.2 Digital Output Conversion 29

7 Appendix C. DMU Command Quick Reference 30

8 Appendix D. Warranty and Support Information 31

8.1 Customer Service 31
8.2 Contact Directory 31
8.3 Return Procedure 31
8.3.1 Authorization 31
8.3.2 Identification and Protection 32
8.3.3 Sealing the Container 32
8.3.4 Marking 32
8.3.5 Return Shipping Address 32
8.4 Warranty 32

About this Manual

The following annotations have been used to provide additional information.

NOTE

Note provides additional information about the topic.

☑ EXAMPLE

Examples are given throughout the manual to help the reader understand the terminology.

IMPORTANT

This symbol defines items that have significant meaning to the user

WARNING

The user should pay particular attention to this symbol. It means there is a chance that physical harm could happen to either the person or the equipment.

The following paragraph heading formatting is used in this manual:

1 Heading 1

1.1 Heading 2

1.1.1 Heading 3

Normal

1 Introduction

1.1 The DMU™ Series Motion and Attitude Sensing Units

This manual explains the use of the IMU700CA and the VG700CA.

The IMU700CA is six-axis measurement systems designed to measure linear acceleration along three orthogonal axes and rotation rates around three orthogonal axes. It uses three accelerometers and three angular rate sensors to make a complete measurement of the dynamics of your system.

The VG700CA has similar sensor architecture as the IMU700CA but is designed to provide stabilized pitch and roll in dynamic environments. The VG700CA is the solid state equivalent of a vertical gyro/artificial horizon display.

The AHRS Series products are nine-axis measurement systems that combine accelerometers, rate sensors, and magnetometers to create a complete attitude and heading reference system. The operation of the AHRS models are covered in separate user's manuals.

The Dynamic Measurement Unit (DMU) series are low power, fast turn on, reliable and accurate solutions for a wide variety of stabilization and measurement applications.

All DMU products have both an analog outputs and an RS-232 serial link. Data may be requested via the serial link as a single measurement or streamed continuously. The analog outputs are fully signal conditioned and may be connected directly to a data acquisition device.

The Crossbow DMUs employ on board digital processing to provide application-specific outputs and to compensate for deterministic error sources within the unit. The DMUs accomplish these tasks with an analog to digital converter and a high performance Digital Signal Processor.

The VG700CA and IMU700CA use the same accurate, reliable MEMS acceleration sensors as the IMU300 Series, IMU400 Series. The VG700CA and IMU700CA use fiber-optic gyros to provide angular rate measurements that are more accurate and subject to less drift than the silicon based rate sensors.

1.2 Package Contents

In addition to your DMU sensor product you should have:

- **1 CD with GyroView Software**

GyroView will allow you to immediately view the outputs of the DMU on a PC running Microsoft® Windows™. You can also download this software from Crossbow's web site at http://www.xbow.com.

- **1 Digital Signal Cable.**

This links the DMU directly to a serial port. Only the transmit, receive, power, and ground channels are used. The analog outputs are not connected.

- **1 DMU Calibration Sheet**

The Digital Calibration Sheets contains the custom offset and sensitivity information for your DMU. The calibration sheet is not needed for normal operation as the DMU has an internal EEPROM to store its calibration data. However, this information is useful when developing your own software to correctly scale the output data. Save this page!

- **1 DMU Users Manual**

This contains helpful hints on programming, installation, valuable digital interface information including data packet formats and conversion factors.

2 Quick Start

2.1 GyroView Software

Crossbow includes GyroView software to allow you to use the DMU right out of the box and the evaluation is straightforward. Install the Gyro View software, connect the DMU to your serial port, apply power to your unit and start taking measurements.

2.1.1 GyroView Computer Requirements

The following are minimum capabilities that your computer should have to run GyroView successfully:

- CPU: Pentium-class
- RAM Memory: 32MB minimum, 64MB recommended
- Hard Drive Free Memory: 15MB
- Operating System: Windows 95, 98, Me, NT4, 2000

2.1.2 Install GyroView

To install GyroView in your computer:

1. Put in CD "Support Tools".
2. Find the GyroView folder. Double click on the setup file.
3. Follow the setup wizard instructions. You will install GyroView and a LabView 6 Runtime Engine. You need both.

If you have any problems or questions, you may contact Crossbow directly.

2.2 Connections

The DMU is shipped with a cable to connect the DMU to a PC COM port.

1. Connect the 15-pin end of the digital signal cable to the port on the DMU.
2. Connect the 9-pin end of the cable to the serial port of your computer.
3. The additional black and red wires on the cable supply power to the DMU. Match red to (+) power and black to (-) ground. The input voltage supply for the VG700CA and IMU700CA should be 10 - 30 VDC at 0.75 A. See the specifications for your unit.

WARNING

Do not reverse the power leads! Applying the wrong power to the DMU

can damage the unit; Crossbow is not responsible for resulting damage to the unit.

NOTE

The analog outputs from the DMU are unconnected in this cable.

2.3 Setup GyroView

With the DMU connected to your PC serial port and powered, open the GyroView software.

1. GyroView should automatically detect the DMU and display the serial number and firmware version if it is connected.
2. If GyroView does not connect, check that you have the correct COM port selected. You find this under the "DMU" menu.
3. Select the type of display you want under the menu item "Windows". Graph displays a real time graph of all the DMU data; FFT displays a fast-fourier transform of the data; Navigation shows an artificial horizon display.
4. You can log data to a file by entering a data file name. You can select the rate at which data is saved to disk.
5. Under "DMU" or "DMU Controls", you can set the erection rate and rate sensor zeroing time. Enter a value, and click the button. **The value is not sent until the button is clicked.**
6. If the status indicator says, "Connected", you're ready to go. If the status indicator doesn't say connected, check the connections between the DMU and the computer; check the power; check the serial COM port assignment on your computer.

2.4 Take Measurements

Once you have configured GyroView to work with your DMU, pick what kind of measurement you wish to see. "Graph" will show you the output you choose as a strip-chart type graph of value vs. time. "FFT" will show you a real-time fast Fourier transform of the output you choose. "Navigation" will show an artificial horizon and the stabilized pitch and roll output of the DMU. ("Navigation" does not work with the IMU models.)

Let the DMU warm up for 30 seconds when you first turn it on. You should zero the rate sensors when you first use the DMU. Set the DMU down in a stable place. On the main control panel, enter a value into the "zero avg time" box. "3" will work well. Click the "Z" button. This measures the rate sensor bias and sets the rate sensor outputs to zero. The zeroing command turns on the high pass filter rate bias estimation that takes

approximately 3 minutes. The DMU needs to be held still (motionless) during zeroing operation. The "zero" command is discussed more in "The 'Zero' Command" section. Now you're ready to use the DMU!

3 DMU Details

3.1 DMU Coordinate System

The DMU will have a label on one face illustrating the DMU coordinate system. With the connector facing you, and the mounting plate down, the axes are defined as:

X-axis – from face with connector through the DMU.

Y-axis – along the face with connector from left to right.

Z-axis – along the face with the connector from top to bottom.

The axes form an orthogonal right-handed coordinate system. Acceleration is positive when it is oriented towards the positive side of the coordinate axis. For example, with the DMU sitting on a level table, it will measure zero g along the x- and y-axes and +1 g along the z-axis. Gravitational acceleration is directed downward, and this is defined as positive for the DMU z-axis.

The angular rate sensors are aligned with these same axes. The rate sensors measure angular rotation rate around a given axis. The rate measurements are labeled by the appropriate axis. The direction of a positive rotation is defined by the right-hand rule. With the thumb of your right hand pointing along the axis in a positive direction, your fingers curl around in the positive rotation direction. For example, if the DMU is sitting on a level surface and you rotate it clockwise on that surface, this will be a positive rotation around the z-axis. The x- and y-axis rate sensors would measure zero angular rate, and the z-axis sensor would measure a positive angular rate.

Pitch is defined positive for a positive rotation around the y-axis (pitch up). Roll is defined as positive for a positive rotation around the x-axis (roll right).

The angles are defined as standard Euler angles using a 3-2-1 system. To rotate from the body frame to an earth-level frame, roll first, then pitch, then yaw.

3.2 Connections

The IMU700CA and VG700CA have a male DB-15 connector. The signals are as shown in Table 1. All analog outputs are fully buffered and are designed to interface directly to data acquisition equipment. See "Analog Output" for details.

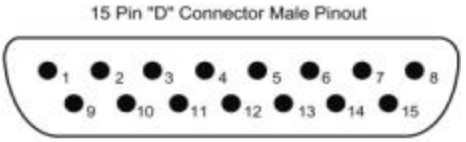


Table 1. DMU Connector Pin Out

Pin	Signal
1	RS-232 Transmit Data
2	RS-232 Receive Data
3	Positive Power Input (+)
4	Ground
5	X-axis accelerometer Analog voltage[1]
6	Y-axis accelerometer Analog voltage[1]
7	Z-axis accelerometer Analog voltage[1]
8	Roll rate analog voltage[2]
9	Pitch rate analog voltage[2]
10	Yaw rate analog voltage[2]
11	NC – factory use only
12	Roll analog voltage (VG Series only)/X-axis accel scaled analog voltage[3]
13	Pitch analog voltage (VG Series only)/Y -axis accel scaled analog voltage[3]
14	Unused/Z-axis accel scaled analog voltage[3]
15	NC – factory use only

Notes:

1. The accelerometer analog voltage outputs are the raw sensor output. These outputs are taken from the output of the accelerometers.
2. The rate sensor analog voltage outputs are scaled to represent °/s. These outputs are created by a D/A converter.
3. Actual output depends on DMU measurement mode. The pitch and roll analog outputs are scaled to represent degrees. The accelerometer analog outputs are scaled to represent G's. These outputs are created by a D/A converter.

The serial interface connection is standard RS-232. On a standard DB-25 COM port connector, make the connections per Table 2.

Table 2. DB-25 COM Port Connections

COM Port Connector			DMU Connector	
Pin #	Signal		Pin #	Signal
2	TxD		2	RxD
3	RxD		1	TxD
7	GND*		4	GND*

*Note: Pin 4 on the DMU is data ground as well as power ground.

On a standard DB-9 COM port connector, make the connections per Table 3.

Table 3. DB-9 COM Port Connections

COM Port Connector			DMU Connector	
Pin #	Signal		Pin #	Signal
2	RxD		1	TxD
3	TxD		2	RxD
5	GND*		4	GND*

*Note: Pin 4 on the DMU is data ground as well as power ground.

Power is applied to the DMU on pins 3 and 4. Pin 4 is ground; Pin 3 should have 10-30 VDC unregulated at 0.75 A. If you are using the cable supplied with the DMU, the power supply wires are broken out of the cable at the DB-9 connector. The red wire is connected to VCC; the black wire is connected to the power supply ground. DO NOT REVERSE THE POWER LEADS.

The analog outputs are unconnected in the cable we supply. The analog outputs are fully buffered and conditioned and can be connected directly to an A/D. The analog outputs have a 1 kΩ resistor in series with each output to protect the outputs from a short circuit. This should be taken into account when using data acquisition devices with moderate input impedances (less than 10 kΩ).

3.3 Interface

The serial interface is standard RS-232, 38400 baud, 8 data bits, 1 start bit, 1 stop bit, no parity, and no flow control.

Crossbow will supply DMU communication software examples written in LabView. Source code for the DMU serial interface can be obtained via the web at http://www.xbow.com. The source code has a .vi file format and requires a National Instruments LabView 5.0 license to use.

The DMU baud rate can be changed. To change the baud rate, follow this procedure:

1. Start with the DMU connected to the serial interface, with your software set to the default baud rate of 38400.
2. Send the ASCII character "b" (62 hex) to the DMU. In a terminal program like Windows HyperTerminal or ProComm, this means simply type the letter "b". The DMU is case sensitive.
3. Now change the baud rate of your terminal software.
4. Send the ASCII character "a". The DMU will detect the character and automatically match the baud rate your software is using. Upon successful operation, the DMU will return the character "A" at the new baud rate.
5. You can now use the DMU at the new baud rate.

The new baud rate setting is not permanent; therefore, this process must be repeated after any power reset.

3.4 Measurement Modes

The VG700CA is designed to operate as vertical gyros; however, you can also use them as six-axis sensors. The VG700CA can be set to operate in one of three modes: voltage mode, scaled sensor mode, or angle (VG) mode. The IMU700 Series of products do not support angle mode. The measurement mode selects the information that is sent in the data packet over the RS-232 interface. See "Data Packet Format" for the actual structure of the data packet in each mode.

3.4.1 Voltage Mode

In voltage mode, the analog sensors are sampled and converted to digital data with 1 mV resolution. The digital data represents the direct output of the sensors. The data is 12-bit, unsigned. The value for each sensor is sent as 2 bytes in the data packet over the serial interface. A single data packet can be requested using a serial poll command or the DMU can be set to continuously output data packets to the host.

The voltage data is scaled as:

$$\textbf{voltage} = \textbf{data}*(5\ V)/2^{12},$$

where **voltage** is the voltage measured at the sensor, and **data** is the value of the unsigned 16-bit integer in the data packet. Note that although the data is sent as 16-bit integers, the data has a resolution of only 12 bits.

The DMU rate sensor and angle analog outputs are **not** enabled in this mode. Only the linear accelerometer analog output on pins 5 – 7 will be enabled because these signals are taken directly from the accelerometers. See the "Analog Output" section for a complete description of the analog outputs.

3.4.2 Scaled Sensor Mode

In scaled sensor mode, the analog sensors are sampled, converted to digital data, temperature compensated, and scaled to engineering units. The digital data represents the actual value of the quantities measured. A calibration table for each sensor is stored in the DMU non-volatile memory. A single data packet can be requested using a serial poll command or the DMU can be set to continuously output data packets to the host. The data is sent as signed 16-bit 2's complement integers. In this mode, the DMU operates as a six-axis measurement system.

The scaled sensor analog outputs are enabled in this mode. Note that stabilized pitch and roll angles are not available in scaled sensor mode. See the "Analog Output" section for a complete description of the analog outputs.

To convert the acceleration data into G's, use the following conversion:

$$\textbf{accel} = \textbf{data}*(\textbf{GR} * 1.5)/2^{15}$$

where **accel** is the actual measured acceleration in G's, **data** is the digital data sent by the DMU, and **GR** is the G Range for your DMU. (The data is scaled so that1 G = 9.80 m s^{-2}.) The G range of your DMU is the range of accelerations your DMU will measure. For example, if your DMU uses a ±2 G accelerometer, then the G range is 2.

To convert the angular rate data into degrees per second, use the following conversion:

$$\textbf{rate} = \textbf{data}*(\textbf{AR}*1.5)/2^{15}$$

where **rate** is the actual measured angular rate in °/sec, **data** is the digital data sent by the DMU, and **AR** is the Angular rate Range of your DMU. The angular rate range of your DMU is the range of angular rates your DMU will measure. For example, if your DMU uses a ±200 °/s rate sensors, then **AR** range is 200.

◀ NOTE

RR is 200 for all VG700CA and IMU700CAs.

3.4.3 Angle Mode (VG700CA Only)

In angle mode, the DMU will act as a vertical gyro, and output the stabilized pitch and roll angles along with the angular rate and acceleration information. The angular rate and acceleration values are calculated as described in the scaled sensor mode.

The DMU analog outputs are enabled in this mode, including stabilized pitch and roll angles. See the "Analog Output" section for a complete description of the analog outputs.

In angle mode, the DMU uses the angular rate sensors to integrate over your rotational motion and find the actual pitch and roll angles. The DMU uses the accelerometers to correct for the drift in the rate sensors. This is the modern equivalent of an analog vertical gyro that used a plumb bob in a feedback loop to keep the gyro axis stabilized to vertical. The DMU takes advantage of the rate gyros' sensitivity to quick motions to maintain an accurate orientation when accelerations would otherwise throw off the accelerometers' measurement of the DMU orientation relative to gravity. The DMU uses the accelerometers to provide long term stability to keep the rate gyro drift in check.

The DMU gives you control over the weighting between the accelerometers and rate gyros through a parameter called the "erection rate." This term is derived from analog vertical gyros, and refers to the rate at which the system can pull the gyro spin axis back to vertical as measured by gravity. With a small erection rate, you are depending more on the rate gyros than the accelerometers; with a large erection rate, you are forcing the rate gyros to follow the accelerometer measurement of vertical more closely. In general, for dynamic measurements, you will want a low erection rate. But the erection rate should always be greater than the drift rate of the rate gyros. The erection rate is discussed in section 4.2 in more detail.

The VG700CA outputs the pitch and roll in the digital data packet in angle mode. To convert the digital data to angle, use the following relation:

$$\textbf{angle} = \textbf{data}*(\textbf{SCALE})/2^{15},$$

where **angle** is the actual angle in degrees (either pitch or roll), and **data** is the signed integer data output in the data packet, and **SCALE** is a constant. **SCALE** = 180^0 for roll and pitch.

3.5 Commands

The DMUs have a simple command structure. You send a command consisting of one or two bytes to the DMU over the RS-232 interface and the DMU will execute the command.

◀ NOTE

The DMU commands are case sensitive!

GyroView is a very good tool to use when debugging your own software. GyroView formulates the proper command structures and sends them over the RS-232 interface. You can use GyroView to verify that the DMU is functioning correctly. GyroView does not use any commands that are not listed here.

3.5.1 Command List

Command	Ping
Character(s) Sent	R
Response	H
Description	Pings DMU to verify communications

Command	Voltage Mode
Character(s) Sent	r
Response	R
Description	Changes measurement type to Voltage Mode. DMU outputs raw sensor voltage in the data packet.

Command	Scaled Mode
Character(s) Sent	c
Response	C
Description	Changes measurement type to Scaled Mode. DMU outputs measurements in scaled engineering units.

Command	Angle Mode
Character(s) Sent	a

Response	A
Description	Changes measurement type to Angle (VG) Mode. DMU calculates stabilized pitch and roll. Also outputs sensor measurements in scaled engineering units.

Command	Polled Mode
Character(s) Sent	P
Response	none
Description	Changes data output mode to Polled Mode. DMU will output a single data packet when it receives a "G" command.

Command	Continuous Mode
Character(s) Sent	C
Response	Data Packets
Description	Changes data output mode to Continuous Mode. DMU will immediately start to output data packets in continuous mode. Data rate will depend on the measurement type the DMU is implementing (Raw, Scaled, or Angle). Sending a "G" will return DMU to Polled Mode.

Command	Request Data
Character(s) Sent	G
Response	Data Packet
Description	"G" requests a single data packet. DMU will respond with a data packet. The format of the data packet will change with the measurement mode (Raw, Scaled, or Angle). Sending the DMU a "G" while it is in Continuous Mode will place the DMU in Polled Mode.

Command	Set Erection Rate (VG Series only)
Character(s) Sent	T<x>

Response	none
Description	The T command sets the vertical gyro erection rate. The argument of the command <x> is a single binary byte that represents the value you want to set as the erection rate. The units are in degrees per minute. For example, if you wanted to set the erection rate to 50 deg/min, you would send the command T<50>, which in hex would be 54 32.

Command	Calibrate Rate Sensor Bias
Character(s) Sent	z<x>
Response	Z
Description	Measure the bias on each rate sensor and set as the new zero. **The DMU should be still (motionless) during the zeroing process.** The argument of the command <x> is a single binary byte that the DMU ignores and is part of the legacy code, any single byte character can be sent. The zeroing command turns on the high-pass filter rate estimation that takes approximately 3 minutes.

Command	Query DMU Version
Character(s) Sent	v
Response	ASCII string
Description	This queries the DMU firmware and will tell you the DMU type and firmware version. The response is an ASCII string. The exact string will vary according to the DMU type and version.

Command	Query Serial Number
Character(s) Sent	S
Response	Serial number packet
Description	This queries the DMU for its serial number. The

	DMU will respond with a serial number data packet that consists of a header byte (FF), the serial number in 4 bytes, and a checksum byte. The serial number bytes should be interpreted as a 32-bit unsigned integer. For example, the serial number 9911750 would be sent as the four bytes 00 97 3D C6.
Command	Request Auto Baud Rate
Character(s) Sent	b
Response	-
Description	This starts the auto baud rate detection process. This will allow you to change the DMU baud rate from its default. This change will not affect the default settings. 1. Start with communications program and DMU at same baud rate. 2. Send "b" to the DMU. 3. Change the baud rate of your communications program. 4. Send "a" to the DMU. The DMU will respond with "A" at the new baud rate when a successful detection of the new baud rate is completed.

3.6 Data Packet Format

In general, the digital data representing each measurement is sent as a 16-bit number (two bytes). The data is sent MSB first then LSB.

In voltage mode, the data is sent as unsigned integers to represent the range 0 – 5 V.

In scaled and angle mode, the data generally represents a quantity that can be positive or negative. These numbers are sent as a 16-bit signed integer in 2's complement format. The data is sent as two bytes, MSB first then LSB.

In scaled and angle mode, the timer information and temperature sensor voltage are sent as unsigned integers.

The order of data sent will depend on the selected operating mode of the DMU.

Each data packet will begin with a header byte (255) and end with a checksum. The checksum is calculated in the following manner:

1. Sum all packet contents *except* header and checksum.
2. Divide the sum by 256.
3. The remainder should equal the checksum.

Table 4 shows the data packet format for each mode.

Table 4. Data Packet Format (v1.2)

Byte	VG Mode	Scaled Sensor Mode	Voltage Mode
0	Header (255)	Header (255)	Header (255)
1	Roll Angle (MSB)	Roll Rate (MSB)	Gyro Voltage X (MSB)
2	Roll Angle (LSB)	Roll Rate (LSB)	Gyro Voltage X (LSB)
3	Pitch Angle (MSB)	Pitch Rate (MSB)	Gyro Voltage Y (MSB)
4	Pitch Angle (LSB)	Pitch Rate (LSB)	Gyro Voltage Y (LSB)
5	Roll Rate (MSB)	Yaw Rate (MSB)	Gyro Voltage Z (MSB)
6	Roll Rate (LSB)	Yaw Rate (LSB)	Gyro Voltage Z (LSB)
7	Pitch Rate (MSB)	Acceleration X (MSB)	Accel Voltage X (MSB)
8	Pitch Rate (LSB)	Acceleration X (LSB)	Accel Voltage X (LSB)
9	Yaw Rate (MSB)	Acceleration Y (MSB)	Accel Voltage Y (MSB)
10	Yaw Rate (LSB)	Acceleration Y (LSB)	Accel Voltage Y (LSB)
11	Acceleration X (MSB)	Acceleration Z (MSB)	Accel Voltage Z (MSB)
12	Acceleration X (LSB)	Acceleration Z (LSB)	Accel Voltage Z (LSB)
13	Acceleration Y (MSB)	Temp Voltage (MSB)	Temp Voltage (MSB)
14	Acceleration Y (LSB)	Temp Voltage (LSB)	Temp Voltage (LSB)
15	Acceleration Z (MSB)	Time (MSB)	Time (MSB)
16	Acceleration Z (LSB)	Time (LSB)	Time (LSB)
17	Temp Voltage (MSB)	Checksum	Checksum
18	Temp Voltage (LSB)		
19	Time (MSB)		
20	Time (LSB)		
21	Checksum		

NOTE

The header byte FF will likely not be the only FF byte in the data packet. You must count the bytes received at your serial port and use the checksum to ensure you are in sync with the data sent by the DMU. This is especially critical when using the continuous data packet output mode.

3.7 Timing

In some applications, using the DMU's digital output requires a precise understanding of the internal timing of the device. The processor internal to the DMU runs in a loop - collecting data from the sensors, processing the data, then collecting more data. The data is reported to the user through a parallel process. In continuous mode, the system processor activity is repeatable and accurate timing information can be derived based purely on the overall loop rate.

The unit goes through three processes in one data cycle. First, the sensors are sampled. Second, the unit processes the data for output. After processing the data, the DMU will make another measurement while presenting the current measurement for output. Third, the unit actually transfers the data out; either over the RS-232 port, or onto the analog outputs.

In the case of the analog output, the data is presented immediately on the analog output pins after the data processing step is over. In the case of the digital data, the data is transferred only if the previous data packet is cleared.

A time tag is attached to each data packet. The time tag is simply the value of a free running counter at the time the A/D channels are sampled. The clock counts down from 65,535 to 0, and a single tick corresponds to 0.79 microseconds. The timer rolls over approximately every 50 milliseconds.

3.8 Temperature Sensor

The DMU has an onboard temperature sensor. The temperature sensor is used to monitor the internal temperature of the DMU to allow for temperature calibration of the sensors. The sensor is specified to be within ±2% accurate over the DMU temperature operating range. The DMU reads and outputs the temperature sensor voltage in the digital data packet with 12-bit precision.

The temperature sensor voltage is sent in the data packet scaled as:

$$\mathbf{V_{temp}}\,(\mathrm{V}) = \mathbf{data} * 5/4096,$$

where **data** is the 16-bit unsigned integer sent as the temperature information in the data packet. (The DMU uses two full bytes to express the data, but it is really scaled to 12 bits.)

Calculate the temperature with the following calibration:

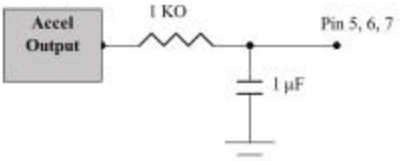
$$T\,(^{\circ}\mathrm{C}) = 44.4\,(^{\circ}\mathrm{C/V}) * (\mathbf{V_{temp}}\,(\mathrm{V}) - 1.375\ \mathrm{V}),$$

where $\mathbf{V_{temp}}$ is the temperature sensor voltage sent in the DMU data packet.

The DMU temperature sensor is internal to the DMU, and is not intended to measure the ambient temperature. The internal temperature of the DMU may be as much as 15°C higher than the ambient temperature.

3.9 Analog Output

The DMU provides six fully conditioned analog outputs in scaled mode – three accelerometer voltages and three rate sensor voltages. In angle mode, the scaled accelerometer voltages are replaced with the pitch and roll analog voltages. In all modes, the raw accelerometer sensor output is also available. The analog signals can be connected directly to an A/D or other data acquisition device without further buffering. The input impedance of your data acquisition device should be greater than 10 kΩ for the DAC outputs and relatively higher impedance for raw analog outputs. The circuit diagram for the raw accelerometer outputs (Pin 5, 6 and 7) is shown below:



The DMU must be set to scaled sensor mode or angle mode to enable the scaled analog signals.

3.9.1 "Raw" Accelerometer Voltage

The analog outputs from the accelerometers are taken directly from the sensor through a buffer. They are "raw" in the sense that they do not represent a calculated or calibrated value. You will need the zero bias point and scale factor given on the DMU calibration sheet to turn the analog voltage into an acceleration measurement.

To find the acceleration in G's, use the following conversion:

$$\textbf{accel}\ (G) = (\mathbf{V_{out}}(V) - \textbf{bias}(V)) * \textbf{sensitivity}(G/V),$$

where **accel** is the actual acceleration measured, $\mathbf{V_{out}}$ is the voltage at the analog output, **bias** is the zero-G bias voltage, and **sensitivity** is the scale factor in units G/volts.

For example, if the x-axis of your accelerometer has a zero-G bias of 2.512 V, a sensitivity of 1.01 G/V, and you measure 2.632 V at the analog output, the actual acceleration is (2.632 V – 2.512 V)*1.01 G/V = 0.121 G. The "raw" accelerometer voltages will always be available on pins 5- 7.

3.9.2 Scaled Accelerometer Voltage

In scaled mode, the DMU will create scaled analog accelerometer voltages on pins 12 – 14. These analog voltages reflect any calibration or correction the DMU applies to the accelerometer data. The analog voltage is created

by an internal D/A converter using the digital data available to the DSP. The data is scaled to the range ±4.096 V with 12-bit resolution. You do not need to use the calibration data that came with the DMU to use these outputs – the DMU is already applying the calibration stored in its EEPROM to the data.

To find the acceleration in G's, use the following conversion:

$$\textbf{accel}\ (G) = \textbf{GR} * 1.5 * \mathbf{V_{out}}(V) / 4.096\ V,$$

where **accel** is the actual acceleration measured, $\mathbf{V_{out}}$ is the voltage at the analog output and **GR** is the G range of your sensors. The G range is listed on the calibration sheet. For example, if your DMU has ±2 G accelerometers, **GR** is 2.

3.9.3 Scaled Rate Sensor Voltage

The DMU will output analog voltages representing the rate sensor measurement on pins 8 – 10 in both scaled sensor mode and angle mode.

The analog outputs for the angular rate signals are not taken directly from the rate sensors; they are created by a D/A converter internal to the DMU. The output range is ±4.096V with 12-bit resolution. The analog data will represent the actual measured quantities, in engineering units, not the actual voltage at the sensor output. To convert the analog output to a sensor value use the following relation:

$$\textbf{rate} = \textbf{AR} * 1.5 * \mathbf{V_{out}}\ (V) / 4.096\ V,$$

where **rate** is the actual measured rate in units °/s, **AR** is the angular rate range of your sensor and $\mathbf{V_{out}}$ is the measured voltage at the analog output.

For example, if your DMU has a ±200 °/s rate sensor, and the analog output for that sensor is –1.50 V, the value of the measurement is 200 (°/s)*1.5*(-1.50)/4.096 = 109.86 °/s.

NOTE

AR is 200 for all VG700CA and IMU700CAs.

3.9.4 Stabilized Pitch and Roll Voltages (VG models)

In angle mode, the DMU outputs the stabilized pitch and roll angle analog voltages on pins 12 and 13. The analog pitch and roll outputs are created by the DMU internal D/A. The voltage output will be in the range ±4.096 V with 12-bit resolution. The output is scaled so that full scale is 180° for roll (90^0 for VG700CA) and 90^0 for the pitch. To convert the voltage to an actual angle, use the following conversion:

$$\textbf{angle} = \textbf{FA} * \mathbf{V_{out}}\ (V) / 4.096\ V,$$

where angle is the actual pitch or roll **angle** in degrees, **FA** is the full-scale angle and $\mathbf{V_{out}}$ is the analog pitch or roll voltage measured. **FA** is 90^0 for roll and pitch.

3.10 Adaptive-T Algorithm (for VG700 Series, installed at Crossbow factory)

There is no one optimal erection rate for all environments. A high erection rate is better when you are closer to a static situation, and a low erection rate is better when you are in a dynamic situation. Crossbow has developed an algorithm to automatically switch the erection rate (the T parameter) based on the dynamics measured by the DMU. This algorithm is referred to as adaptive-T and is implemented as default at the factory. An overview of the algorithm is presented below; note that the user still has a certain amount of control over the adaptive-T function.

When the unit is powered up and initialized, and the adaptive-T-Setting feature has been chosen, the unit will default to adaptively tune the T-Setting between a maximum T-Setting of 20, and a minimum T-Setting of 1. . The user has the ability to change the effect of the adaptive T function through the T-Setting command as follows:

The user selected T-Setting sets the upper end of the adaptive T algorithm, which then tunes the T-Setting between a T-Setting of 1 and the chosen T-Setting by scaling the setting based on sensed accelerations and the yaw gyro measure of the turn rate. For instance, during large accelerations (high-G maneuvers) or fast turns, the T-setting will be set to a value of 1, and during low accelerations and straight motion the T-Setting will be set to the value chosen by the user. In this way the T-Setting chosen controls the maximum T-Setting that the algorithm will use. While the adaptive-T algorithm offers a hands-off approach to the T-Setting problem, some control over the algorithm is still allowed. The user should still evaluate the performance of the algorithm in each application to achieve the best results.

4 DMU Operating Tips

4.1 The "Zero" Command

The "z<x>" command is used to zero the angular rate sensor biases. This command does not "zero" the angle output! This should be an essential part of your strategy in using the DMU effectively. Stabilized pitch and roll angles are calculated by integrating the output of the angular rate sensors. Rate sensors are subject to small offsets in the angular rate measurement. A constant offset error in angular rate will integrate into an error in angle that increases linearly with time resulting in angular drift. The VG~~76~~00AA uses accelerometers to correct the calculated angle, but in a dynamic situation, the accelerometers will be an inaccurate indication of the angle due to motional accelerations. The DMU rate sensors should therefore be zeroed to maintain the best accuracy.

Zeroing the rate sensors allows you to use a smaller value for the erection rate (T-Setting), which gives you better performance in dynamic environments.

The rate sensors need to be zeroed more often when subject to large shocks or extremes of temperature.

The DMU unit should be still (motionless) during the zeroing process, but need not be level. You should let the DMU warm-up for 5 minutes before issuing the zero command. Zeroing the DMU turns on the high-pass filter rate bias estimation that takes approximately 3 minutes. The zeroing command does not level the stabilized angle output.

Remember that the DMU does not store the rate sensor zero calibration in non-volatile memory. If you cycle power to the DMU, it loses the zero calibration. Ideally, you would issue the zero command every time you power on the DMU. Also ideally, you would let the DMU warm up for 5 minutes before zeroing the rate sensors.

If you find that the DMU zeroing algorithm does not work well in your particular application, please contact Crossbow to discuss possible options.

4.2 The Erection Rate (VG700CA only)

The erection rate parameter controls the weighting between the rate gyro sensors and the accelerometers. This is the rate at which the direction of vertical as measured by integrating the rate gyros is forced to agree with the direction of vertical as measured by the accelerometers. The erection rate is specified in degrees per minute. The erection rate must be higher than the drift rate of the rate gyros, or the calculated angles will drift off with increasing error. If the erection rate is too high, however, the calculated angles will be forced to follow the accelerometers too closely. This will lead to inaccuracies when the unit is under dynamic conditions.

One way to start is to set the erection rate about twice as fast as the worst rate gyro drift rate. This is appropriate for a dynamic environment, when the unit will be under significant acceleration. Estimate the drift rate by looking at the offset on the rate gyro output. Use the zero command first to zero the rate gyros. The rate gyro output is in degrees per second; the erection rate is set in degrees per minute. So take the rate gyro offset; multiply by 60 to turn it into degrees per minute; multiply by two and use this as a starting value for the erection rate. As an example, if the rate sensor offset is 0.1 degrees per second, we would set the erection rate to 0.1 x 60 x 2 = 12. The stabilized pitch and roll output will be responsive to actual rotations, and relatively insensitive to linear accelerations.

You can set the T-Setting in a qualitative way using GyroView. Graph the pitch and roll. Zero the rate sensors. Start with the T-Setting at about 100. Lower the T-Setting in increments of 10 – 20 until the roll and/or pitch starts to drift. When the angle outputs start to drift, the T-Setting is just a bit lower than the rate sensor offset. Increase the T-Setting by about 5 if you have a VG700CA. This should keep the angle outputs stable.

If you expect the DMU to be subject to changing temperatures, or to have to operate for long periods without re-zeroing, you should increase the T-Setting further. You may have to experiment some to find the best erection rate for your situation.

If the DMU is used in a less dynamic environment, the erection rate can be set much higher. The DMU angles will stabilize quicker to the gravity vector. So if the motion is slow, or if you sit in one position for a long time, then you should probably use a high erection rate.

A more advanced approach to the erection rate would take advantage of both regimes of operation. Use a low erection rate when the unit is subject to dynamic motion; use a high erection rate when the unit is relatively stable. You can use the DMU itself to distinguish between the two cases by looking for changes in the accelerometer outputs. For example, in an airplane, you could use a low erection rate when the airplane executes a banked turn; and a high erection rate (100+) when the plane is flying straight and level.

Unfortunately, there is no single ideal erection rate for all applications. We can suggest a starting point based on past experience with similar applications, but you should be prepared to experiment some in the beginning to find the best setup for your DMU in your application.

4.3 Mounting the DMU

The DMU should be mounted as close to the center of gravity (CG) of your system as possible. This will minimize any "lever effect". If it is not mounted at the center of gravity, then rotations around the center of gravity

will cause the DMU accelerometers to measure acceleration proportional to the product of the angular rate squared and the distance between the DMU and the CG.

The DMU will measure rotations around the axes of its sensors. The DMU sensors are aligned with the DMU case. You should align the DMU case as closely as possible with the axes you define in your system. Errors in alignment will contribute directly into errors in measured acceleration and rotation relative to your system axes. The sides of the DMU case are used as reference surfaces for aligning the DMU sensor axes with your system.

The DMU should be isolated from vibration if possible. Vibration will make the accelerometer readings noisy, and can therefore affect the angle calculations. In addition, if the magnitude of the vibration exceeds the range of the accelerometer, the accelerometer output can saturate. This can cause errors in the accelerometer output.

The DMU case is not weather proof. You should protect the DMU from moisture and dust.

☑ EXAMPLE

4.4 DMU Start Up Procedure

As an example, look at how the DMU might be used on an airplane. Assume a VG700CA is mounted on a small twin-prop plane and will be used to record the plane's attitude during flight. Flights will be 2 – 6 hours long. The VG700CA is mounted near the CG of the plane, and is connected to a laptop serial port during flight.

1. Turn on power to the DMU and let it warm up 5 – 10 minutes. Power can be on to all electronics, but the engines should be off.
2. Zero the rate sensors. Engines are off, so there is no vibration.
3. Change the T-Setting. After zeroing, you should be able to set the T-Setting in the range 5 – 10 for a VG700CA.
4. Start the engines.
5. Start data collection.
6. Proceed with flight.

4.5 Advanced Strategies for Adjusting the Erection Rate (VG models)

The DMU attitude estimation algorithm is divided into two separate entities. Gyro angular rate information is integrated in time to propagate the DMU body attitude with respect to the tangent plane. If the initial attitude of the vehicle was known exactly and if the gyros provided perfect

readings then this integration process would suffice. However, the initial state is seldom known to great precision, especially a vehicle's attitude, and the gyros usually provide corrupted data. Rate gyro bias, bias drift, misalignment, acceleration (G-sensitive), nonlinear (square term), and scale factor errors will be present in the angular rate measurements. The largest error is typically associated with the bias and bias drift terms. Without a correction algorithm and separate independent sensors, the attitude estimation algorithm would diverge off the true trajectory. Accelerometers provide the separate measurements, which help keep the attitude estimates on track.

The correction algorithm involves deriving an estimate of the roll and pitch angle from the accelerometer's gravity reference, comparing this estimate to the gyro propagated quaternion Euler angles, and providing a linear feedback gain to the quaternion propagation to take out the errors observed from the gyro angular rate measurements. The correction feedback is also referred to as the "erection rate" implying that the attitude errors are erected out by moving the estimated orientation more towards the absolute attitude measurements derived from the accelerometer measurements. It is also given the name T-Setting to describe the user interface which allows the user to command the DMU to use a desired erection rate. Sensed dynamic accelerations can introduce error into the accelerometer absolute attitude reference. The angle calculation algorithm has no way of knowing whether the sensed acceleration change is being caused by an attitude tilt change in the gravity vector, or from external translational accelerations.

For this reason a user selectable erection rate is available which allows for the possibility of a rapidly maneuvering mission. There is a tradeoff between how much error in the gyros the algorithm can overcome with a low erection setting, compared to the errors induced from having a high erection rate while experiencing large maneuvering accelerations. The gyro zeroing command is useful in maintaining the gyro bias errors down to a minimum, which allows a lower T-Setting to be used during the mission. It must be noted that for the zeroing command to work properly, there must no external disturbance to the unit (engine noise, wind disturbance, etc.) and it would be advised to perform a gyro zeroing in the initial phase of the mission when only electrical power is available. If the user has knowledge of the intensity of upcoming maneuvers or complete control of the flight profile, and can maintain constant serial communications with the DMU unit, then an adapted erection setting profile can be developed. An example follows.

☑ EXAMPLE

4.6 Adapted Flight Profile T-Setting

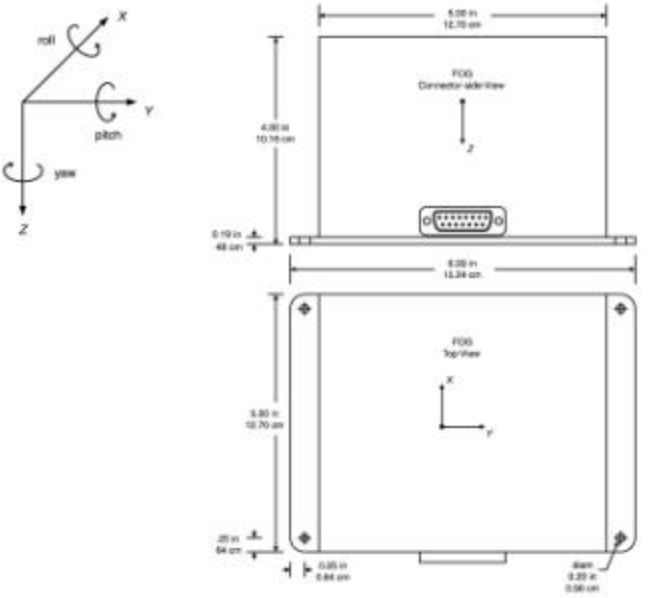
1. Vehicle electric power is applied to the DMU while the vehicle is out of external disturbances (within the hanger for instance).
2. Following a warm-up period, (10 minutes should suffice) a gyro-zeroing command is sent to the unit to average out the gyro biases.
3. Send a T-setting command to set the erection rate at a high setting (T-setting = 100), which should remove any initial attitude errors or drifts.
4. Engine turn-on and rollout onto the runway.
5. Maneuver 1 (Takeoff and climb to desired altitude) – set the erection rate to a low setting (T-setting = 7).
6. Maneuver 2 (1^{st} Coast Phase) – set the erection rate to a high setting (T-setting=100).
7. Maneuver 3 (45 degree heading change) – set the erection rate to a low setting (T-setting = 7).
8. Maneuver 4 (2^{nd} Coast Phase) – set the erection rate to a high setting (T-setting=100).
9. Maneuver 5 (180 degree turn and altitude change – very fast 20 second maneuver) – set the erection rate to an even lower setting since the maneuver is short and the dynamics are large (T-setting = 4).
10. Maneuver 6 (3^{rd} Coast Phase) – set the erection rate to a very high setting to remove any gyro saturation or acceleration saturation from the previous high dynamic maneuver (T-setting=150), and then set the erection rate back to a high setting (T-setting=100).
11. Maneuver 7 (Altitude descent and landing) – set the erection rate to a low setting (T-setting = 7).
12. Maneuver 8 (Runway taxi and stop) – set the erection rate to a high setting (T-setting = 100).

The profile above can be used as an example to produce an adapted erection rate profile to achieve the best possible performance from the DMU. A constant erection rate would not allow the DMU to perform as well because of the highly dynamic environment. A high erection rate would result in very large errors during the high acceleration maneuvers; a low erection rate might not recover from a large gyro bias drift or saturation of the rate sensors because of very large dynamics. Since every flight profile is different, this approach necessitates careful erection rate profile planning.

If enough care is taken, active control of the erection rate will provide the best performance.

5 Appendix A. Mechanical Specifications

5.1 IMU700CA and VG700CA Outline Drawing



6 Appendix B. DMU Output Quick Reference

GR is the G-range of the accelerometers. For example, if your DMU has ±2 G accelerometers, GR = 2.

RR is the rate range of the rate sensors. For example, if your DMU has ±200°/s rate sensors, RR = 200.

6.1 Analog Output Conversion

Accelerometer

Use sensitivity, offset from calibration sheet. Output is raw sensor voltage.

Pin 5	X axis accelerometer, raw
Pin 6	Y axis accelerometer, raw
Pin 7	Z axis accelerometer, raw

Rate Sensor

Rate (°/s) =
V_{out}(V) *** RR * 1.5/4.096**

Pin 8	Roll rate sensor
Pin 9	Pitch rate sensor
Pin 10	Yaw rate sensor

Accelerometer (Scaled Mode only)

Accel (G) =
V_{out} (V) *** GR * 1.5/4.096**

Pin 12	X axis accelerometer
Pin 13	Y axis accelerometer
Pin 14	Z axis accelerometer

Roll, Pitch (Angle Mode only)

Angle (°) = **V_{out}** (V) *** 90/4.096**

Pin 12	Roll Angle
Pin 13	Pitch Angle

6.2 Digital Output Conversion

Data is sent as 16-bit signed integer for all but Temperature. Temperature sensor data is sent as unsigned integer.

Acceleration

Accel (G) **= data * GR * 1.5/2^{15}**

Roll, Pitch (Angle Mode)

Angle (°) **= data * 180/2^{15}**

Rate

Rate (°/s) **= data * RR * 1.5/2^{15}**

Temperature

Temperature (°C) =
[(data * 5/4.096) – 1.375]*44.44

7 Appendix C. DMU Command Quick Reference

Command (ASCII)	Response	Description
R	H	Ping: Pings DMU to verify communications.
r	R	Change to Voltage Mode.
c	C	Change to Scaled Sensor Mode.
a	A	Change to Angle Mode (VG Mode).
P	None	Change to polled mode. Data packets sent when a G is received by the DMU.
C	None	Change to continuous data transmit mode. Data packets streamed continuously. Packet rate is dependent on operating mode. Sending "G" stops data transmission.
G	Data Packet	Get Data: Requests a packet of data from the DMU. Data format depends on operating mode.
T <0-255>*	None	2-byte command sequence that changes the vertical gyro erection rate.
z <0-255>*	Z	Calibrate and set zero bias for rate sensors by averaging over time. The argument of the command <x> is a single binary byte that the DMU ignores and is part of the legacy code, any single byte character can be sent. Unit should be still during zeroing.
b	Change baud rate	Autobaud detection. Send "b"; change baud rate; send "a", DMU will send "A" when new baud rate is detected.
S	ASCII String	Query DMU serial number. Returns serial number as 32 bit binary number.
v	ASCII String	Query DMU version ID string. Returns ASCII string.

*Note: argument of command is sent as a single hex byte, not as an ASCII character.

8 Appendix D. Warranty and Support Information

8.1 Customer Service

As a Crossbow Technology customer you have access to product support services, which include:

- Single-point return service
- Web-based support service
- Same day troubleshooting assistance
- Worldwide Crossbow representation
- Onsite and factory training available
- Preventative maintenance and repair programs
- Installation assistance available

8.2 Contact Directory

United States: Phone: 1-408-965-3300 (7 AM to 7 PM PST)
Fax: 1-408-324-4840 (24 hours)
Email: techsupport@xbow.com

Non-U.S.: refer to website www.xbow.com

8.3 Return Procedure

8.3.1 Authorization

Before returning any equipment, please contact Crossbow to obtain a Returned Material Authorization number (RMA).

Be ready to provide the following information when requesting a RMA:

- Name
- Address
- Telephone, Fax, Email
- Equipment Model Number
- Equipment Serial Number
- Installation Date
- Failure Date
- Fault Description
- Will it connect to GyroView?

8.3.2 Identification and Protection

If the equipment is to be shipped to Crossbow for service or repair, please attach a tag TO THE EQUIPMENT, as well as the shipping container(s), identifying the owner. Also indicate the service or repair required, the problems encountered, and other information considered valuable to the service facility such as the list of information provided to request the RMA number.

Place the equipment in the original shipping container(s), making sure there is adequate packing around all sides of the equipment. If the original shipping containers were discarded, use heavy boxes with adequate padding and protection.

8.3.3 Sealing the Container

Seal the shipping container(s) with heavy tape or metal bands strong enough to handle the weight of the equipment and the container.

8.3.4 Marking

Please write the words, "***FRAGILE, DELICATE INSTRUMENT***" in several places on the outside of the shipping container(s). In all correspondence, please refer to the equipment by the model number, the serial number, and the RMA number.

8.3.5 Return Shipping Address

Use the following address for all returned products:

Crossbow Technology, Inc.
41 E. Daggett Drive
San Jose, CA 95134
Attn: RMA Number (XXXXXX)

8.4 Warranty

The Crossbow product warranty is one year from date of shipment.

Crossbow Technology, Inc.
41 E. Daggett Drive
San Jose, CA 95134
Phone: 408.965.3300
Fax: 408.324.4840
Email: info@xbow.com
Website: www.xbow.com